Meeting of the US Nuclear Data Network
Brookhaven National Laboratory
National Nuclear Data Center
April 16-17, 2001

Training Sessions
Topics for Discussion

1. <u>DDEP Evaluations into ENSDF</u> (Helmer)
   General Policies.
   Conversion Coefficients and Derived Quantities

2. <u>Half-life</u> (Helmer)
   Discrepant data
   Various Types of Averages

3. <u>β^- and β^+ Decay</u> (Browne)
   Level Feedings. Transition Intensity Balances. The GTOL program.
   Annihilation Radiation. β^+ Branching. The LOGFT program.

4. <u>Electron Capture Decay</u> (Browne)
   EC/β^+ ratios
   X Rays. The RADLST program.
   The use of X-ray intensities for verifying decay-scheme consistency.

5. <u>Gamma Rays</u> (Browne, Helmer)
   Energies. New Evaluated Standards (Helmer)
   Intensities. Averaging. The LWEIGHT program. (Browne)
   Multipolarities. Mixing Ratios. (Browne)
   Decay-Scheme Normalization. Examples. (Browne)
   Absolute Intensities. Uncertainties. The GABS program (Browne)
   Conversion Coefficients. Theoretical Values. Current Status. (Browne)

Edgardo Browne

Isotopes Project

Lawrence Berkeley National Laboratory

April 16-17, 2001

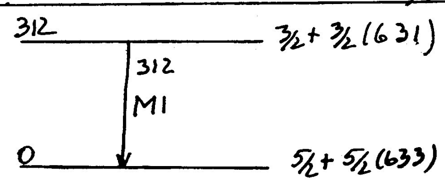
Theoretical Conversion Coefficients

1. F. Rösel et al., At. Data and Nucl. Data Tables 21, 92 (1978
   $Z \geq 30$

2. I. M. Band et al., At. Data and Nucl. Data Tables 18, 433 (1976,
   $Z < 30$

Interpolation Program ICC (Yakushev and Coursol).

Nuclear Penetration Effects



$J\pi \; K \; (N n_z \Lambda)$

$\Delta\Lambda = 2$ (forbidden)

The conversion coefficient is:

$$\beta = \beta_0 \left(1 + B_1 \lambda + B_2 \lambda^2\right)$$

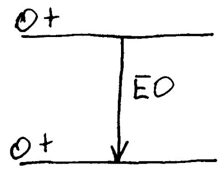
β_0 is the conventional conv. coeff.
B_1 and B_2 are parameters tabulated in Nucl. Data. Tables A6, 1 (1969).

$\lambda = \dfrac{\langle J' | P_1 | J \rangle}{\langle J' | M_{1\gamma} | J \rangle}$ is the penetration parameter.

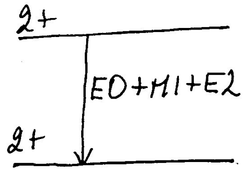
$\langle J' | P_1 | J \rangle$ is the M1 Penetration Matrix Element

$\langle J' | M_{1\gamma} | J \rangle$ is the Reduced Matrix Element for γ-ray emission.

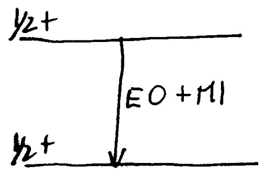
More about multipolarities



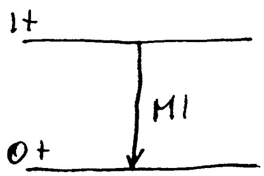
$|J_i-J_f| \le \ell \le |J_i+J_f|$; $0 \le \ell \le 0$; $\ell = 0$



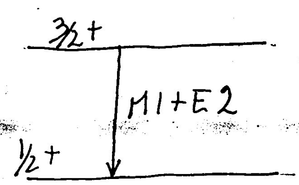
$|2-2| \le \ell \le |2+2|$; $0 \le \ell \le 4$; $\ell = 0, 1, 2,$



$|\frac{1}{2}-\frac{1}{2}| \le \ell \le |\frac{1}{2}+\frac{1}{2}|$; $0 \le \ell \le 1$; $\ell = 0, 1$



$|1-0| \le \ell \le |1+0|$; $1 \le \ell \le 1$; $\ell = 1$



$|\frac{3}{2}-\frac{1}{2}| \le \ell \le |\frac{3}{2}+\frac{1}{2}|$; $1 \le \ell \le 2$; $\ell = 1, 2$

Conventions

M1 – Definite M1 mult.
(M1) – Uncertain M1 mult.
M1 (+E2) – Definite M1 with possible E2 mixing.
[M1] – Assumed M1 mult.

Multipolarities and Mixing Ratios

1. From conversion-electron data.
2. From $\gamma\gamma(\theta)$

Mixing Ratio $\Rightarrow$ $\delta^2 = \dfrac{\langle E2\rangle^2 E_\gamma^5}{\langle M1\rangle^2 E_\gamma^3} = \dfrac{TP(E2)}{TP(M1)}$

Competition: M1 E2 M3 E4 ... (rotational E2)
E1 M2 E3 M4 ... (delayed level,

$$TP = TP(E2) + TP(M1) = (1+\delta^2)\,TP(M1)$$

$\therefore$

$$TP(M1) = \frac{1}{1+\delta^2}\,TP \qquad (\delta = 0 \rightarrow \text{PURE } M1)$$

$$TP(E2) = \frac{\delta^2}{1+\delta^2}\,TP \qquad (\delta = \infty \rightarrow \text{PURE } E2)$$

Case 1. We measured $\alpha(\text{exp})$. Deduce δ^2.

$$I_e = I_\gamma(M1)\,\alpha^{th}(M1) + I_\gamma(E2)\,\alpha^{th}(E2)$$

$$\alpha(\text{exp}) = \frac{I_e}{I_\gamma} = \frac{I_\gamma(M1)}{I_\gamma}\,\alpha^{th}(M1) + \frac{I_\gamma(E2)}{I_\gamma}\,\alpha^{th}(E2)$$

But $I_\gamma(M1) = \dfrac{1}{1+\delta^2}\,I_\gamma$ and $I_\gamma(E2) = \dfrac{\delta^2}{1+\delta^2}\,I_\gamma$

$$\therefore \quad \alpha(\text{exp}) = \frac{1}{1+\delta^2}\left(\alpha^{th}(M1) + \delta^2\,\alpha^{th}(E2)\right)$$

or

$$\boxed{\delta^2 = \frac{\alpha^{th}(M1) - \alpha(\text{exp})}{\alpha(\text{exp}) - \alpha^{th}(E2)}}$$

Case 2. We measured $R = \frac{I_{L1}}{I_{L3}}$. Deduce δ^2.

$$I_{L1} = I_\gamma(M1)\,\alpha^{th}_{L1}(M1) + I_\gamma(E2)\,\alpha^{th}_{L1}(E2)$$

$$I_{L3} = I_\gamma(M1)\,\alpha^{th}_{L3}(M1) + I_\gamma(E2)\,\alpha^{th}_{L3}(E2)$$

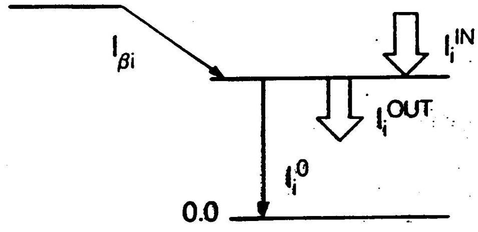
Also $I_\gamma(E2) = \frac{\delta^2}{1+\delta^2} I_\gamma$; $I_\gamma(M1) = \frac{1}{1+\delta^2} I_\gamma$

$\therefore$

$$\boxed{\frac{\delta^2}{1+\delta^2} = \frac{R\,\alpha^{th}_{L3}(M1) - \alpha^{th}_{L1}(M1)}{\alpha^{th}_{L1}(E2) - \alpha^{th}_{L1}(M1) + R\left[\alpha^{th}_{L3}(M1) - \alpha^{th}_{L3}(E2)\right]}}$$

% E2 is $100 \times \frac{\delta^2}{1+\delta^2}$; % M1 $= 100 \times \frac{1}{1+\delta^2}$

γ-ray intensity balance

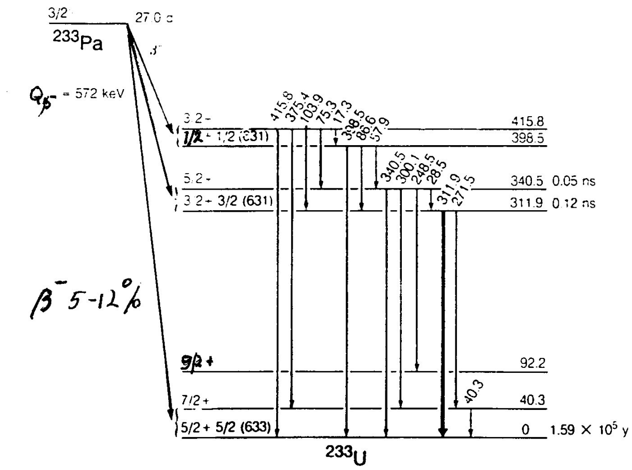


The corresponding normalizing factor is

$$N = \frac{100}{\sum_i \Delta_i} = \frac{100}{D + \sum_i I_i^0}$$

$$\Delta_i = I_i^{OUT} + I_i^0 - I_i^{IN}$$

$$D = \sum_i (I_i^{OUT} - I_i^{IN}) \equiv 0 \quad \text{ALWAYS !!}$$



$$\sum_i I_{\gamma i}(1+\alpha_i)_{gs+40} = 102 \pm 2 \%$$

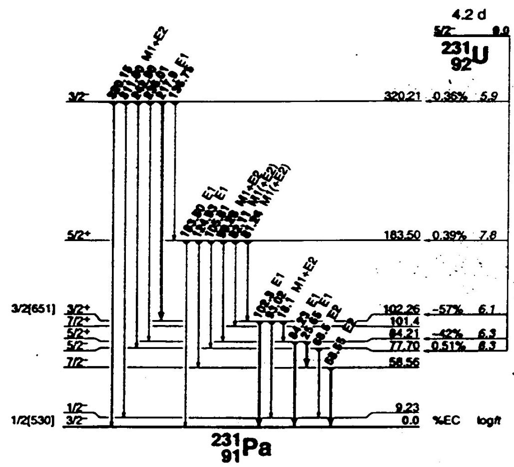
using $I_\gamma(312) = 38.6 \pm 0.5 \%$ (Gehrke et al.)

What went wrong ?

α_{300}, α_{312}, α_{340} are $\approx 18\%$ lower than expected

Nuclear Penetration Effects.

2. Using X-ray intensity to normalize a decay scheme



$$\left.\right\}\ \frac{EC(K)}{EC(\text{TOTAL})} = 0.59$$

$$\omega_K = 0.972$$

Fig. 4. ^{231}U electron-capture decay scheme. Gamma rays measured in this work are shown with thicker arrows; other data are from refs. [3,11]. Electron-capture branches per 100 decays of ^{231}U and log *ft* values are from gamma-ray transition probability balances (see Table 3).

$I_\gamma(25) = 100\ (6)$; $I_\gamma(84) = 50\ (3)$; $I_{KX} = 390\ (14)$

$B_K = 115.6$ keV (most KX rays originated from atomic vacancies created by the EC process)

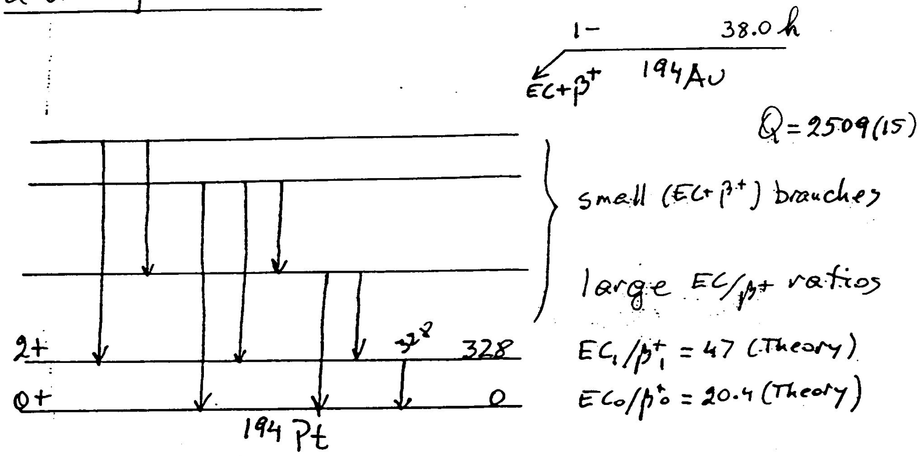
$$\text{Total number of vacancies} = \frac{I_{KX}}{\omega_K \cdot \frac{EC(K)}{EC(\text{TOTAL})}} = 680\ (33)$$

$$N = \frac{100}{680\ (33)} = 0.147\ (7)$$

So:

$$I_\gamma(25) = 100\ (6) \times 0.147\ (7) = 15\ (1)\ \%$$
$$I_\gamma(84) = 50\ (3) \times 0.147\ (7) = 7.5\ (6)\ \%$$

3. Using annihilation radiation to normalize a decay scheme.



All I_γ's are on a relative scale $(I_\gamma(328) = 100)$

Measured $I(511\ \gamma^{\pm})/I_\gamma(328) = 0.058\ (4)$

So $I(\beta^+, \text{TOTAL}) = \frac{1}{2} \times 100 \times 0.058\ (4) = 2.9\ (2)$.

β^+ decay populates the first two levels (approximation)

$I(\beta_0^+) + I(\beta_1^+) = 2.9\ (2)$

From γ-ray intensity balance : $I(EC_1) + I(\beta_1^+) = 49\ (5)$

Using theory : $I_{EC_1}/\beta_1^+ = 47 \longrightarrow I(\beta_1^+) = \frac{49}{48} = 1.02$

Therefore, $I(\beta_0^+) = 2.9\ (2) - 1.02 = 1.9$,

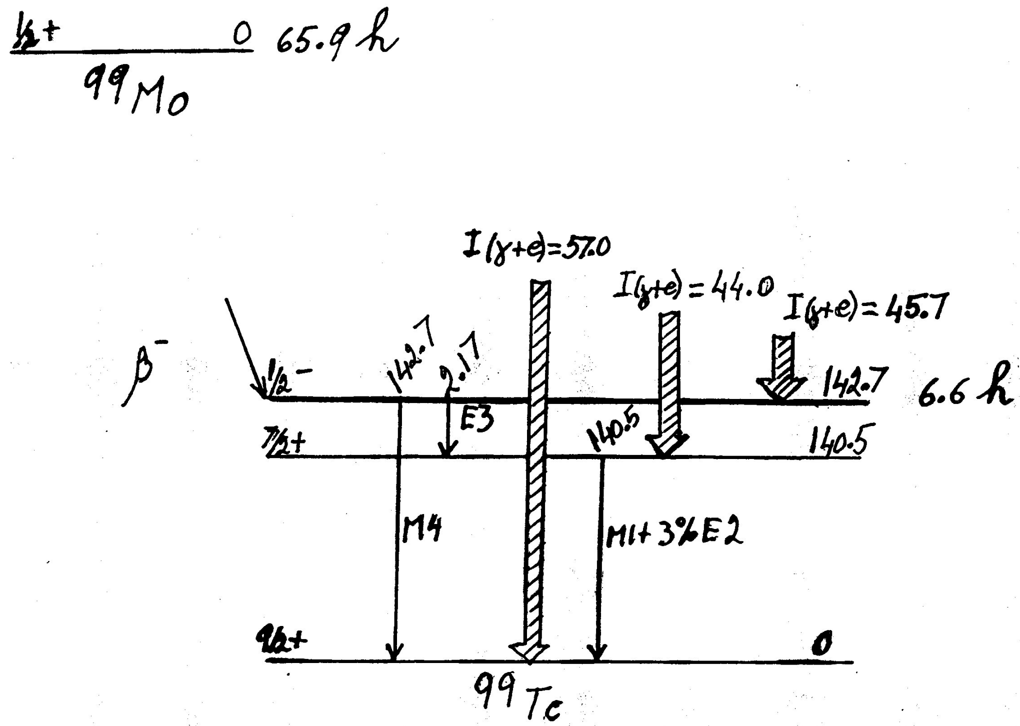
Using theory, $I_{EC_0}/I_{\beta_0^+} = 20.4 \longrightarrow I(EC_0) = 38.8$

EC+β^+ branch to ground state $= 38.8 + 1.9 = 40.7$

From γ-ray intensity balance :

$$\Big(\underbrace{\sum_i I_{\gamma_i}(1+\alpha_i)}_{123} + 40.7\Big) N = 100\% \longrightarrow \boxed{N = \frac{100}{163.7} = 0.61}$$

$I_\gamma(328) = 100 \times 0.61 = 61\%$

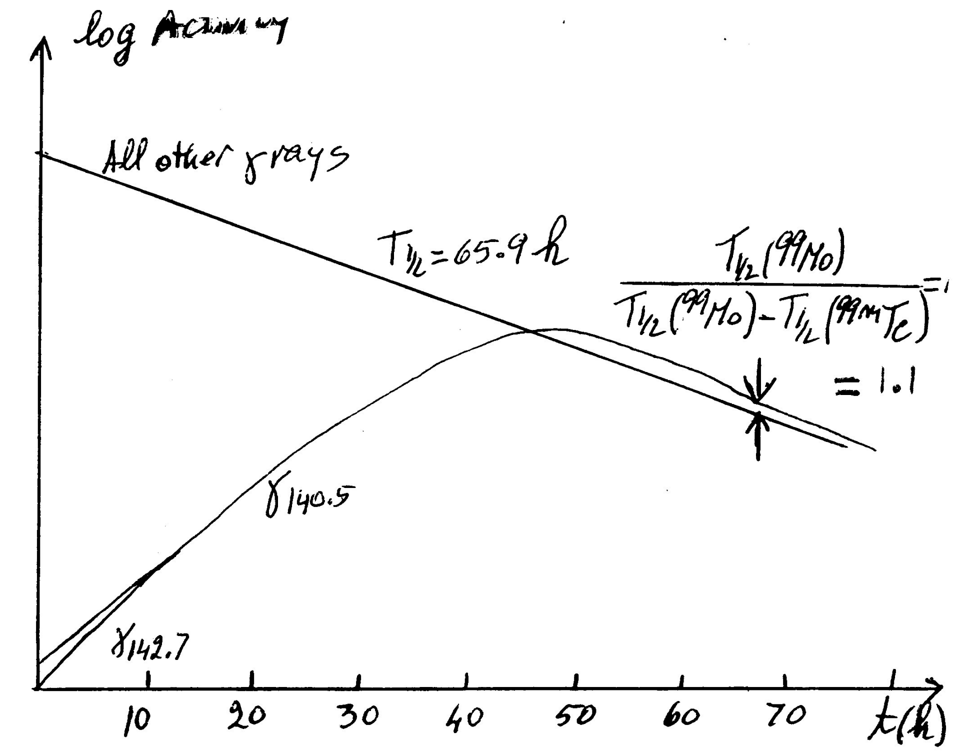


Equilibrium Intensities

$I(\gamma+e)(140.5) = 82.7(12)$

$I(\gamma+e)(142.7) = 7.3(7)$

$$F = \frac{T_{1/2}(^{99}Mo)}{T_{1/2}(^{99}Mo) - T_{1/2}(^{99m}Tc)} = 1.10$$



log Activity
All other γ rays
$T_{1/2} = 65.9\ h$
$\frac{T_{1/2}(^{99}Mo)}{T_{1/2}(^{99}Mo) - T_{1/2}(^{99m}Tc)} = 1.1$
$\gamma_{140.5}$
$\gamma_{142.7}$
10
20
30
40
50
60
70
t(h)

Decay Scheme Normalization

$$\left[I^{*}_{(\gamma+e)}(142.7) + I^{*}_{(\gamma+e)}(140.5) + I_{(\gamma+e)gs}\right] \times N = 100$$

$$I^{*}_{(\gamma+e)}(142.7) = 7.3(7)/F = 7.3(7)/1.1 = 6.6(6)$$

$$I^{*}_{(\gamma+e)}(140.5) = 827(12)/F = 827(12)/1.1 = 752(11)$$

$$I_{(\gamma+e)gs} = 57.0(8)$$

$$N = \frac{100}{816(11)} = 0.1226(17)$$

$$P_\gamma(140.5) = 739(11) \times 0.1226(16) = 90.6\,\%$$

$$I_\gamma(739.5) = 100 \longrightarrow P_\gamma(739.5) = 12.26(17)\%$$

What is the uncertainty in $P_\gamma(140.5)$?

Is it $P_\gamma(140.\ ) = 90.6(18)$? That is, 2%?

$$P_\gamma(140.5) = \frac{I_\gamma(140.5) \times 100}{\frac{1}{1.1}\left[I_\gamma(140.5)(1+\alpha_{140.5}) + I_\gamma(142)(1+\alpha_{142})\right] + I_{(\gamma+e)gs}}$$

$$= 100\left(1.017(3) + 0.0099(9) + 0.077(2)\right)^{-1}$$

$$= 90.6(3)\%$$

β^- Feeding to 142.7-keV level

$$I\beta^- = I^*_{\gamma_{142.7}}(1+\alpha_{142.7}) + I^*_{\gamma_{2.17}}(1+\alpha_{2.17}) - I_\gamma(\gamma+e)_{142.7}$$

$$I^*_{\gamma_{2.17}}(1+\alpha_{2.17}) = I_{\gamma_{140.5}}(1+\alpha_{140.5})/1.1 - I_\gamma(\gamma+e)\,140.5$$

$$= \frac{739(11)\times 1.119(3)}{1.1} - 44.0 = 708$$

So,

$$I\beta^- = \frac{0.174(14)\times 41.9(8)}{1.1} + 708 - 45.7 = 669$$

$$P\beta^- = 669 \times 0.1226 = 82.0\%$$

* Corrected for equilibrium

REPORT FILE - PROGRAM GABS

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Current date: 03/22/2001
 99MO B- DECAY                 1992GO22,1990ME15
NR=     0.1226  18     BR=      1.00

FOR INTENSITY UNCERTAINTIES OF GAMMA RAYS NOT USED IN CALCULATING NR,
COMBINE THE UNCERTAINTY IN THE RELATIVE INTENSITY IN QUADRATURE
WITH THE UNCERTAINTY IN THE NORMALIZING FACTOR (NR x BR).
FOR THE FOLLOWING GAMMA RAYS:

E= 140.511    1  %IG=82.4  4 PER 100 DIS.(Compare with 82.4 17)
E= 142.675   25 %IG=0.0194 18 PER 100 DIS.(Compare with 0.0194 18)
E= 181           %IG=6.08 12 PER 100 DIS.(Compare with 6.08 13)
E= 761.77     8 %IG=0.0023 14 PER 100 DIS.(Compare with 0.0023 14)
```

Absolute Equilibrium Intensities

$P_\gamma(140.5) = 82.4(4) \times 1.1 = 90.6\ (4)\ \%$

$P_\gamma(142.7) = 0.0194(18) \times 1.1 = 0.0213(20)\ \%$